Anthropogenic factors affecting the status of salmon stocks in Pacific Northwest watersheds

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BIOGRAPHY

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ABSTRACT

Anthropogenic effects on watersheds are important in explaining the decline of Pacific Northwest salmon stocks. Associations were tested between thirteen anthropogenic variables in 202 watersheds in Washington, Oregon, Idaho and California and the stock status of summer, spring and fall Chinook *Onchorhynchus tshawytsha*, coho *O. kisutch*, and winter steelhead *O. mykiss*. Summer Chinook had the highest risk status, followed by spring Chinook, coho, fall Chinook and winter steelhead. Difference in life history characteristics helped explain some of the results. Significant associations ($P < 0.001$) were found between the status of salmon and all anthropogenic variables, but dams were the only variable associated with higher risk stocks for all species and races. The combination of dams, subdvision development, USFS land, and watershed groups, correctly classified 95% of summer Chinook stocks. Number of dams and absence of wild and scenic rivers correctly classified 86% of spring Chinook stocks. Watershed groups, human population, and number of dams correctly classified 77% of coho stocks. Number of dams, USFS land and lack of forest area correctly classified 71% of fall Chinook stocks. Indian tribal land, human population and number of dams correctly classified 86 % of winter steelhead stocks. Coastal stocks presented an average status of "special concern" and were associated with land use variables. Columbia Basin stocks averaged a "moderate to high risk of extinction" status and were associated with dams, wild and scenic rivers, and land use variables. Results between status of salmon and anthropogenic variables can be used to prioritize action towards salmon recovery.

INTRODUCTION

The most commonly cited causes of decline in salmon populations are the four H's: habitat, hydropower, hatcheries, and harvest. Areas that lack human activities are normally associated with healthier salmon (Magnuson and Hilborn 2003). This study attempts to quantify human interactions with salmon in a large scale. Freshwater habitat, hydropower, and hatcheries as well as presence or absence of watershed groups and India tribes in watersheds where salmon spawn are statistically tested against with the status of salmon stocks.

Habitat is addressed by categorizing watersheds as to their relative amount of urban population and subdivision development, agricultural and forest type land. Urbanization, farming and logging alter habitat by simplifying river channels, removing riparian vegetation, and, in the case of urbanization and farming, introducing pollutants into the water, all of which may lead to lower environmental productivity (Frissell 1992; FEMAT 1993; Fresh and Lucchetti 1999; Bradford and Irvine 2000; Pess et al. 2002; Regetz 2003). The effect of hydropower on salmon is addressed in this study by the number of dams below a watershed and the relative amount a watershed is blocked by a dam. Dams, constructed for hydropower and irrigational purposes, may greatly affect salmon by blocking spawning and juvenile migration, increasing temperatures and decreasing water flows in impounded lakes, and by increasing predation at bypass systems (Lichatowich and Mobrand 1995; National Research Council 1996).

Humans have attempted to address anthropogenic effects on salmon through habitat restoration projects, alterations to dams, hatchery supplementation, and reduced harvest rates. This study looks at presence or absence of Indian tribes, watershed groups and hatcheries in salmon watersheds. Indian tribes, local, state, and federal resource agencies, environmental organizations, and landowners, functioning independently or as part of cooperative efforts of watershed groups have worked to develop and implement plans for habitat improvement and salmon recovery (For the Sake of the Salmon 1995; Columbia River Inter-Tribal Fish Commission 1996; Oregon Plan 1997; Johnson and Campbell 1999; McGinnis et

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14. ABSTRACT

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al. 1999; Doyle et al. 2000; Glavin 2002). Some actions taken to improve fish habitat have been successful (Paulsen and Fisher 2005), while other mitigation strategies for habitat loss, such as hatchery supplementation, have had mixed results. On one hand hatchery salmon supplement wild salmon for commercial and recreational purposes, while on the other hand they compete with wild salmon for food and shelter, can promote outbreeding depression and reduced fitness through domestication selection (Independent Scientific Advisory Board 2002), and can introduce domestic diseases into wild stocks (Hilborn 1992; Lichatowich 1999). The existence of hatcheries has allowed increased fishing pressure on wild salmon while masking the decline of wild salmon stocks (Lichatowich 1999).

Pacific salmon have a generalized life cycle characterized by anadromy, homing, and semelparity (death after first spawning) for most species. The status of multiple species and races of salmon were analyzed against anthropogenic variables to determine whether differences in their status and the way they are associated with anthropogenic variables could be understood by comparing their life history traits such as variation in habitat requirements for spawning, time spent in freshwater prior to migrating to sea, geographic distribution, and the time of year when they return to spawn (Barnhart 1986; Groot and Margolis 1991; Healey 1991; Sandercock 1991; Weitkamp et al. 1995; Busby et al. 1996; Myers et al. 1998). Variable life history traits allow populations to accommodate to changing environments with varying success (Table 1).

The species and races of salmon chosen for this study were spring, summer, and fall Chinook *Onchorhynchus tshawytsha*, coho *O. kisutch*, and winter steelhead *O. mykiss.* Chinook salmon are commonly differentiated into two groups: a stream-type, which resides in freshwater for a year or more after emergence, and an ocean-type, which migrates to the ocean within the first year (Healey 1991; Myers et al. 1998) (Table 1). Chinook are also differentiated into races based on the time of year during which they return to spawn. Summer and spring Chinook are normally described as stream-type, while fall Chinook are described as ocean-type (Healey 1991). There are, however, regional life history differences as well. For example, summer Chinook on the Columbia River exhibit an ocean-type life history, while their counterparts on the Snake River exhibit a stream-type life history (Myers et al. 1998). Coho salmon occur in most coastal streams and in some Columbia Basin streams. Because many Columbia Basin coho stocks have gone extinct while coastal coho are in better shape, coho was one of the species chosen to address anthropogenic differences between Columbia Basin and coastal salmon. Most coho salmon mature during their third year of life and arrive at their rivers of origin during late summer and autumn. They generally begin their upstream migration when there is a seasonal large increase in river flow (Sandercock 1991; Weitkamp et al. 1995). Steelhead are commonly differentiated into two groups: winter steelhead and summer steelhead. For the purpose of this study, only winter steelhead were chosen since summer steelhead have a very limited geographic range. Steelhead may spawn repeatedly during a lifetime and have a more variable life history than that of most other salmon, including regional variability according to age-structure and number of spawnings (Barnhart 1986; Busby et al. 1996).

Out of the 202 watersheds chosen for this study there are two distinct regions, the Columbia Basin and the coastal watersheds (Figure 1). These two regions differ in ecoregional characteristics, such as climate, soils, and vegetation, as well as land use activities (Bailey 1995; Omernik 1995; Thiele et al. 1995). Ecoregional characteristics have been shown to be important determinants of the success of salmon species and races in coping with anthropogenic modifications of their natural environment (FEMAT 1993; Lichatowich et al. 1995; Omernik 1995), and have been used to describe Evolutionary Significant Units (ESU) for salmon (Weitkamp et al. 1995; Busby et al. 1996; Myers et al. 1998). The stock concept (Ricker 1972) and the watershed are the basis for organizing the data in this study. Stocks of salmon are defined at various watershed scales depending on the detail of information available about the populations.

The objectives of this study were to compare life cycle factors of salmon relative to the way they are associated with anthropogenic variables and to address regional factors differentiating coastal and Columbia Basin salmon stocks. The major contribution of this paper is the large scope of the study and the inclusion of multiple variables for hundreds of watersheds comparing life history characteristics of three salmon species (five races). While many studies have associated anthropogenic variables with salmon decline, most of these covered a smaller area and focused on detailed information about fewer watersheds and fewer anthropogenic variables (Frissell 1992; Botkin et al. 1995; Kostow 1996; Tschaplinski 1999; Bradford and Irvine 2000; Paulsen and Fisher 2001; Pess et al. 2002; Regetz 2003). Efforts have been made to create a plan for testing hypotheses about the multiple causes

Table 1: Freshwater life history characteristics of the five Pacific salmon species and races included in this study. FW = freshwater.

Characteristics	Spring Chinook	Summer Chinook	Fall Chinook	Coho	Winter steelhead
Return to FW	spring	summer	Aug. to Dec.	late summer - fall	variable
Spawning migration	several months	several months	few days or weeks	three months or longer	enter as maturing fish spawning soon
Spawning	Aug/Sep/Oct	fall	Sept. to March	fall	Nov. to April
Spawning Areas	headwater Streams	intermediate Tributaries	large rivers mainstem habitat	small headwater and coastal streams	mostly intermittent coastal streams
Rearing areas	headwater streams	intermediate tributaries	tributaries or estuaries	slower moving sections of stream or coastal lake	shallow water of stream banks
Time spent rearing	about 1 year (variable)	about 1 year (variable)	weeks or a few months in FW or estuary	up to 15 months	1-4 years (most variable)
Other characteristics	more time in FW than fall Chinook	More time in FW than fall Chinook	may rear in estuary to smolt size	Very adaptable "opportunistic"	Possibility of repeat spawning up to 4 times

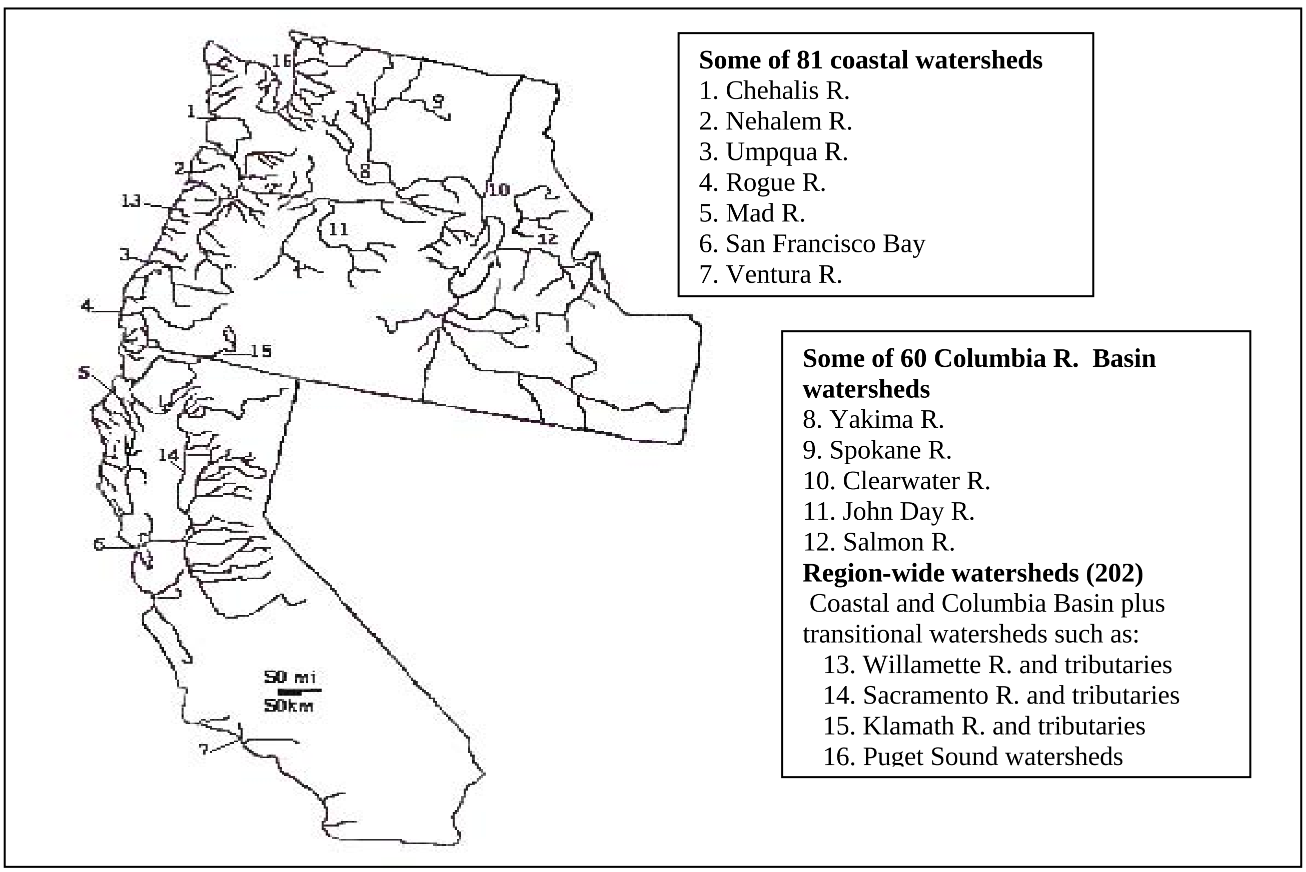

Figure 1: Map showing general distributions of the 202 watersheds in this study (after Myers et al. 1998)

attributed to salmon decline (Marmorek and Peters 2001). The study presented here is unique for several reasons: 1) it included data on the status of multiple species and races of salmon for all the watersheds for which there was information on the status of theses species and races – a total of 202 watersheds; 2) it used both univariate and multivariate statistical tools to characterize associations between salmon and anthropogenic variables; 3) it developed a methodology for collecting and coding anthropogenic data, which can be used to test hypotheses regarding associations between salmon and human activities on their watershed.

METHODS

DATA

The main approach of this study was to compile existing information on spring, summer and fall Chinook, coho, and winter steelhead stocks in watersheds throughout Washington, Oregon, Idaho, and California (Figure 1) for the years 1991 to 1994 and to gather anthropogenic data for these watersheds. The reason for the time frame was the availability of three comprehensive studies on the status of salmon stocks (Nehlsen et al. (1991); Huntington et al. (1994); and Nawa (1995)). Statistical analyses were then used to determine whether the current status of these salmon were associated with specific anthropogenic variables. Stock status was based upon Nehlsen et al. (1991) and Huntington et al. (1994) while data from Nawa (1995) were used to check for consistency between these two reports and, also, to establish a coding system. Nehlsen et al. (1991) is one of the most comprehensive large scale studies of stocks of salmon that are threatened, endangered or at special concern while Huntington et al. (1994) looked at healthy stocks. Including the two sources of data enabled this study to have five categories of salmon status ranging from lowest risk to extinct stocks (Table 2), and later analyze this data against anthropogenic variables to try to explain why some stocks are in better shape than others. I recognize that some of the populations identified have undergone numerous updates since 1994, however the purpose of this study was to determine relationship between the status of salmon between 1991 and 1994 and anthropogenic variables also determine during this period of time. Although the status of salmon for these populations as well as some of the land use variables might have changed, the statistical relationships during that time might still be useful to management.

The greatest challenge was to organize the anthropogenic data into watersheds, since such data generally conform to political boundaries, not to geographical boundaries, which better delineate watersheds. Maps, surveys and published reports were used to classify each watershed according to thirteen anthropogenic variables (Table 3). These variables were coded with a number ranging from 1 to 5 (in most cases) for each of the watersheds, with 1 representing ideal states of variables hypothesized to be associated with lower risk salmon stocks, such as wilderness areas or wild and scenic rivers, and 5 representing the absence of these variables or the presence of other variables hypothesized to be testing associated with higher risk salmon stocks, such as dams, agriculture, urbanization, and hatcheries. For example, if a watershed was entirely (>90% of its area) in agricultural land or blocked by a dam, and a hatchery was present in the watershed, then each anthropogenic variable was coded 5 for that watershed. If a watershed, on the other hand, was entirely located in forest land and hatcheries were absent from the watershed then each variable was coded 1 for that watershed (Table 3).

Table 2: Variable representing categories of stock status for the species and races in this study. Note: source of data: Nehlsen et al. (1991) and Huntington et al. (1994)

Species and races	**Description of variable**
Summer Chinook, Spring Chinook, Fall Chinook, Coho, and Winter Steelhead	Status of the stock falls in one of the following categories: 1 = Stock is at >67% of its original abundance; 2 = Stock is at 10-67% of its original abundance; 3 = Stock is considered "at special concern" or at <10% of its original abundance; 4 = Stock is "at moderate risk of extinction," "at high risk of extinction," or "maybe already extinct;" 5 = Stock is "extinct."

Table 3: Anthropogenic variables chosen for this study, their description, source of data, and map scale (if a map).

Variables	Variable description and categories	Source of data	Map scale
Dam blockage	An estimate of how much of the watershed is blocked by a dam. 5= > 90% of the watershed is blocked by one or more dams; 4= 60% - 90% of the watershed is blocked by one or more dams; 3 = 40% - 60% of the watershed is blocked by one or more dams; 2 = 10% - 40% of the watershed is blocked by one or more dams; 1= no dams in the watershed.	US Department of the Interior - Bureau of Reclamation (1985 and 1995) US Army Corps of Engineers (1990)	1 in = 30 miles; 1 in = 35 miles;
Number of dams	A count of the number of dams below the watershed: from 0 to 12	Same as above	Same as above
Forest land, USFS land, non-USFS land*, wilderness, wild and scenic river, Indian tribe *a reciprocal of USFS land	An estimate of how much of the watershed in forest land: Example: 1 = > 90% of the watershed is in forest land; 2= 60% - 90% of the watershed is in forest land; 3 = 40% - 60% of the watershed is in forest land; 4 = 10% - 40% of the watershed is in forest land; 5= < 10% of the watershed is in forest land.	DeLorme Mapping (1991, 1995 a and b); US Department of Agriculture (1988); US Army Corps of Engineers (1990); and Gousha Company (1995)	1 in = 45 miles; 1 in = 38.5 miles; 1:1,000,000 1 in = 35 miles 1 in = 20 miles
Agricultural land; subdivision development	An estimate of how much of the watershed is in agricultural land. An estimate of the amount of subdivision development, which is defined as "built-up area" (estimated on the number of gridlines on maps): Refer to coding of forest land, with opposite direction (e.g. 5= > 90% of the watershed is in agricultural land)	DeLorme Mapping (1991 and 1995a and b)	1 in = 45 miles; 1 in = 38.5 miles;
Human Population	A relative measure of the number of people inhabiting the watershed: 1 = the watershed is in an uninhabited area or close to very small towns usually in forested area; 2 = outside the boundaries of a moderate sized city or near a city with low human population; 3 = located near cities with moderate human population; 4 = near large cities; 5 = within the boundaries of cities with a very large population;	US Census Bureau (1990); Population Research Center (1997); Used maps cited above to locate cities;	Not a map; 1 in = 45 miles; 1 in = 38.5 miles;
Hatcheries	1 = there is no hatchery in this watershed 5 = there is at least a hatchery in this watershed	Johnson (1990) and Survey response from Mark Committee members (this study)	Not a map
Watershed group	1= a watershed group is known to exist in this watershed 5 = no watershed group is known to exist in this watershed	For the Sake of the Salmon (1995, 1996)	Not a map

Given the myriad of anthropogenic influences to watersheds in the study area, it was hypothesized that: 1) activities that negatively affect salmon, such as dams, agriculture and urbanization, are associated with higher risk salmon stocks; 2) less human activity, such as in wilderness and wild and scenic rivers, or activities promoting healthy watersheds, such as those undertaken by Indian tribes and watershed groups, are associated with lower risk salmon stocks. Because of the direction of the coding, if hypotheses were supported, then positive correlations and coefficients would result.

To address the objective of determining whether there are regional differences in the association between the status of salmon stocks and anthropogenic variables in the watersheds where these salmon spawn I looked at the entire data set (202 watersheds) and two subregions of these, Coast (81 watersheds) and Columbia Basin (60 watersheds) (Figure 1). In doing so, 61 watersheds were eliminated from the subregions because of their transitional nature and the intent to maximize the contrast in order to extract the anthropogenic impacts. Columbia Basin stocks where compared to stocks region-wide and coastal stocks.

STATISTICAL ANALYSES

There were three levels of measurement in the data: nominal - presence or absence of hatcheries and a watershed group; interval - number of dams below a watershed; and ordinal - status of salmon stocks and all other anthropogenic variables, including a qualitative measure of how much of the watershed is dammed (Tables 2 and 3).

SPSS (Statistical Package for Social Sciences) was used for all analyses. Univariate and multivariate statistics, both with parametric and non-parametric tools, were used to test the various hypotheses of this study. While recognizing that parametric statistics are based upon normal distribution, which is normally not the case with ordinal and nominal variables, most of the variables in this study were ordinal divided into five categories (Tables 2 and 3). According to Bernard (1989), ordinal variables divided into at least five categories can be analyzed statistically as interval variables.

A high significance level of $P < 0.001$ was used to assess significant correlations in univariate analyses and $P < 0.01$ for multivariate analyses. Because this is a general study of many watersheds, only the most significant relationships were presented, keeping in mind the high probability of type II error (failure of detecting a significant relationship) exists. Kendall's tau-c, a non-parametric method, tested associations between the status of salmon and each of the anthropogenic variables (Gibbons 1976). Watersheds were also coded for their relative size, which varied from very small creeks, such as Fifteen Mile Creek in the Columbia Basin - coded 1 for watershed size, and Payette River in Washington, coded 2; to large basins, such as the Handford Reach - coded 5 for watershed size (Appendix). Partial correlation with pairwise deletion of missing data was used to control for watershed size (Nie et al. 1975).

Discriminant analysis and logistic regression were used to determine the combination of anthropogenic variables that best explained the status of salmon stocks. Discriminant analysis and logistic regression were used to distinguish two groups of stocks for each of the species and races of salmon (Nie et al. 1975): "lower risk" and "higher risk" stocks. Huntington et al. (1994) described a healthy stock as one which is at 10% or greater of its original abundance, designated in the present study as categories 1 and 2 ("lower risk"). "Higher risk" stocks were designated in the present study as categories 3, 4, and 5. One disadvantage of using discriminant analysis and logistic regression with the anthropogenic variables is the possibility of multicolinearity in watershed data (Ramsey and Schafer 1997). Multicolinearity refers to the situation in which some or all of the independent variables are highly correlated. This was the case with forest variables (USFS land, total forest, wilderness and non-USFS land), dams, USFS land and Indian tribal land, and with subdivision development and human population. Weighting of particular variables to reflect the relative importance of each in relationship to salmon was considered, but not adopted. Such weighting would be arbitrary and would have added to the complexity of analyzing large amounts of data. Although the author recognizes that a "5" for dam blockage is different than a "5" for agriculture, these categories simply mean a qualitative measure of the relative amount of a watershed where this activity is present.

RESULTS

Summer Chinook stocks had the highest risk status region-wide (Table 4). Stocks had an average status of 4.4, meaning moderate to high/risk of extinction, and 55% were already extinct. The higher risk status of stocks region-wide was associated with dam blockage, absence of hatcheries, and absence of a watershed group (Table 5). Number of dams below the watershed, amount of subdivision development,

Table 4: Proportion of stocks in the various status categories region-wide and average status of various species and races of salmon. n= number of stocks, SUCH = summer Chinook, SPCH= spring Chinook, FACH=Fall Chinook, WIST= winter steelhead, WAT= watershed.

Stock Status	SUCH (n= 44)	SPCH (n= 94)	COHO (n= 56)	FACH (n = 80)	WIST (n= 96)	WAT. AVE[a] (n=202)
1 = >67% original abundance	0	0	2%	11%	10%	5%
2 = 10-67% original abundance	5%	5%	16%	34%	34%	17%
3 = Special concern	7%	6%	4%	6%	21%	15%
4 = Mod./ high risk	34%	53%	52%	30%	24%	44%
5 = extinct	55%[b]	35%	27%	19%	10%	20%
Average status [c]	**4.4**	**4.2**	**3.9**	**3.1**	**2.9**	**3.6**

[a] Average status of all species and races combined in each of the watersheds.
[b] Here indicates that out of 44 summer Chinook stocks region-wide, 55% are extinct. Species are sequenced on the basis of average status, from highest to lowest risk.
[c] Average of the status of each of the species from 1(low risk) to 5 (extinct).

Table 5: Significant associations between the species and races of salmon and anthropogenic variables in Coastal Columbia Basin and watersheds region-wide. "Average status" range from 1 for healthy to 5 for extinct. A positive correlation or coefficient means that the association between the status of salmon and the anthropogenic variable was in the direction hypothesized ($p \leq 0.001$ for correlations and $p \leq 0.01$ for multivariate analyses). Statistical analyses for which no significant results were found at this level, were omitted from the table. n = number of stocks, ns= no significant associations, # DAMS = number of dams, DAMS= dam blockage, W&S = wild and scenic rivers, HAT = hatcheries, POP= human population, FOR = total forest, USFS = USFS area, non-USFS = non=USFS area; INDIAN = Indian tribe, SUB = subdivision development, WAT = watershed group, W= Wilk's lambda, class = correctly classified, a = Constant.

Species/ race	Status and statistics	Coast	Columbia Basin	Region-wide
Summer Chinook	**Average status**	3.3 (n = 3)	4.5 (n= 26)	4.4 (n=44)
	Kendall's tau	Too few stocks for meaningful statistical analyses	ns	DAMS (0.5) HAT (-0.5)
	Partial correlation		#DAMS (0.7) WAT (0.5)	DAMS (0.3) HAT (-0.5) WAT (0.3)
	Discriminant analysis		FOR + POP (W = 0.7; class = 88%)	#DAMS+SUB+ USFS+WAT (w=-0.5; class=95%)

		Table 5 (continued)		
Species/ race	**Status and statistics**	**Coast**	**Columbia Basin**	**Region-wide**
Spring Chinook	**Average status** **Kendall's tau**	3.4 (n=12) ns	4.4 (n= 40) DAMS (0.6)	4.2 (n=94) DAMS (0.5) #DAMS (0.4) INDIAN (-0.4)
	Discriminant analysis	W&S (W = 0.9; class = 80%)	WAT + W&S (W = 0.7 ;class = 82%)	S&S+#DAMS (W=0.8; class=83%)
	Logistic regression	ns	ns	(0.3)#DAMS + (0.8)W&S (a=-1.8; class=86%)
coho	**Average status** **Kendall's tau**	3.3 (n = 32) ns	4.8 (n = 16) ns	3.9 (n=56) DAMS (0.7) #DAMS (0.4) INDIAN (-0.4)
	Partial correlation	ns	ns	#DAMS (0.4) non-USFS (0.3) USFS (-0.3)
	Discriminant analyses	WAT + FOR (W =0.5; class. = 84%)	No "lower risk" coho in the Columbia Basin	WAT + POP + #DAMS (w= 0.7; CLASS = 77%)
	Logistic regression	(-1.0)WAT (a= 3.1; class = 87%)	No "lower risk" coho in the Columbia Basin	(-0.5)WAT (a=2.7; class=79%)
Fall Chinook	**Average status** **Kendall's tau**	2.4 (n=48) ns	4.1 (n=17) ns	3.1 (n=80) DAMS (0.4) #DAMS (0.5) Non-USFS (0.3)
	Partial correlation	ns	ns	DAMS (0.2) #DAMS (0.4)
	Discriminant analysis	USFS (W = 0.9; class. = 72%)	ns	DAMS + non-USFS (W = 0.8; class = 63%)
	Logistic regression	ns	ns	(0.8)FOR + (-.08) (USFS) + (0.5)#DAMS (A=1.0; CLASS= 71%)
Winter Steelhead	**Average status** **Kendall's tau**	2.7 (n= 48) HAT (-0.5) WILD (0.4) POP (0.4)	4.0 (n=24) #DAMS (0.8) Non-USFS (0.6)	2.9 (96) DAMS (0.4) #DAMS (0.5) HAT (-0.4) AGR (0.3) INDIAN (0.3)
	Partial correlation	ns	DAMS (0.5)	#DAMS (0.6)
	Discriminant analysis	ns	Non-USFS (W = 0.5; class = 90%)	DAMS + non-USFS (W=0.8; class=82%)
	Logistic regression	ns	ns	(2.0) INDIAN + (1.2)POP + (0.6)#DAMS (a=-13.5;class=86%)

amount of USFS land, and presence or absence of a watershed group in the watershed combined as well as dam blockage and hatcheries combined helped correctly classify the status of summer Chinook stocks region-wide (Table 5). There were too few (3) summer Chinook stocks on the Coast to allow meaningful statistical analyses (Table 5). In the Columbia Basin, summer Chinook stocks were at higher risk in watersheds with more dams and the absence of watershed groups. Greater amount of forestland in the watershed and less human population combined correctly classified Columbia Basin summer Chinook stocks (Table 5).

Spring Chinook were the second highest risk status region-wide (Table 4). Stocks had an average status of 4.2, meaning moderate to high/risk of extinction, and 35% were already extinct. Dam blockage, number of dams, Indian tribal land and USFS land variables were associated with higher risk spring Chinook stocks, while the variable non-USFS area was associated with lower risk stocks region-wide (Table 5). The combined variables indicating number of dams and wild and scenic rivers in the watershed correctly classified spring Chinook stocks region-wide (Table 5). On the Coast, the only variable associated with spring Chinook salmon stocks was wild and scenic river (Table 5). In the Columbia Basin, watershed groups and wild and scenic rivers correctly classified spring Chinook stocks (Table 5).

Coho were the third highest risk status and the highest risk in the Columbia Basin (Tables 4 and 5). Stocks had an average status of 3.9, meaning of special concern and close to moderate to high/risk of extinction, and 27% were already extinct. Greater number of dams, greater proportion of agricultural land, and presence of watershed groups were associated with higher risk coho salmon stocks region-wide, while forest and non-USFS areas were associated with lower risk coho stocks (Table 5). Number of dams below the watershed, presence or absence of a watershed group, and amount of human population, combined, correctly classified coho stocks. Watershed groups and dams were significantly associated with coho (Table 5). On the Coast, presence of watershed groups and low amount of forestland correctly classified coho stocks (Table 5). In the Columbia Basin, all stocks of coho were in the higher risk category, therefore, discriminant and logistic regression could not be used (Table 5).

Fall Chinook stocks had the second lowest risk region-wide and the lowest risk on the Coast (Tables 4 and 5). Stocks had an average status of 3.1 meaning special concern and 19% were already extinct. Number of dams, dam blockage, and USFS area were associated with higher risk salmon while non-USFS area and forest variables were associated with lower risk salmon (Table 5). Forest and dams correctly classified fall Chinook stocks region-wide (Table 5). Fall Chinook stocks were at lower risk in forested watersheds with fewer dams and less USFS land. On the Coast, the only significant variable discriminating fall Chinook stocks was USFS land (Table 5). In the Columbia Basin, there were no significant associations between fall Chinook and anthropogenic variables (Table 5).

Winter steelhead presented the lowest risk stocks region-wide (Table 4). Stocks had an average status of 2.9 meaning close to special concern, and 10% were already extinct. Number of dams, dam blockage, agriculture, and human population were associated with higher risk winter steelhead while hatcheries and Indian tribes were associated with lower risk winter steelhead stocks (Table 5). Number of dams, dam blockage, and the presence of hatcheries correctly classified winter steelhead stocks (Table 5). Dam blockage, Indian tribal land, and population correctly classified winter steelhead stocks (Table 5). On the Coast, hatcheries and wilderness were associated with lower risk winter steelhead and human population with higher risk stocks (Table 5). In the Columbia Basin, number of dams, dams status and watershed groups were associated with higher risk winter steelhead stocks while non-USFS area and Indian tribe were associated with lower risk stocks (Table 5).

DISCUSSION

LIFE HISTORY DIFFERENCES

Length of freshwater phase, season of spawning migration, location of spawning habitat, and other life history characteristics were useful in justifying some of the associations between anthropogenic variables and different species/races of salmon.

Summer Chinook presented the highest risk status region-wide and there were only three summer Chinook stocks reported on the Coast. Season of spawning migration might have contributed to the low status of summer Chinook, when naturally low river flow and high temperatures in the summer are exacerbated by anthropogenic activities such as dams, logging, and urbanization. The status of summer Chinook was mainly associated with dams and hatcheries. Other factors not accounted for in this study, may help explain the poor status of summer Chinook stocks. Bradford (1995) found that

estimates of marine survival for Chinook were much lower than for coho or sockeye, and suggested that the high ocean mortality of Chinook smolts may explain the low survival to maturity of hatchery Chinook salmon.

Spring Chinook was strongly associated with wild and scenic rivers. The fact that only 7% of the 202 watersheds of this study were wilderness areas or wild and scenic rivers could partly explain their relatively poor status when compared to most other species and races of salmon, and the fact the spring Chinook was the only species associated with wild and scenic rivers. This race was also strongly associated with dams. Keefer et al. (2004) found that migration timing of Columbia Basin spring-summer Chinook populations was positively correlated with river discharge, possibly timing their migration to avoid difficult passages and environmental conditions.

Coho was the species and race with the lowest status in the Columbia Basin, with 80% of stocks extinct and an average status close to extinction. Coho presented the highest association with the number of dams below the watershed and dam blockage (Table 5). Coho are referred to as an "opportunistic" species, with the ability to reach headwater streams and take advantage of better spawning habitat (Sandercock 1991), but dams have blocked much of their upstream habitat in the Columbia River Basin. Yet, Lower Columbia coho are extinct due to poor habitat. The status of coho stocks was highly associated with agriculture, forest variables, watershed groups, wilderness, and human population. The location of coho stocks, mainly in small coastal streams, Puget Sound and lower Columbia Basin rivers, coincides with a relatively high degree of urbanization, agriculture, and forest-related activities. Pess et al. (2002) found that coho densities reflect large-scale land-use patterns, with forested areas showing a positive correlation to spawner abundance and agricultural and urban areas showing a negative correlation to spawner abundance. In the Thompson River watershed of British Columbia, coho decline was correlated with both agricultural land use and road density (Bradford and Irvine 2000).

Fall Chinook spends less time in freshwater prior to migrating to sea than spring and summer Chinook or coho. This can serve as a double advantage as fall Chinook spend less time exposed to anthropogenic effects on the watershed and more time feeding in the ocean. Also, their time of spawning migration is relatively more favorable than those for spring and summer Chinook because of increased water flows and decreased temperatures in the fall. One disadvantage to fall Chinook is that only 17% of the historical habitat is currently available for this race in the Snake River (Columbia Basin), while about 62% is still available for spring/summer Chinook and steelhead (Hassemer et al. 1995). It is therefore understandable that dams were the most significant variable associated with the status of fall Chinook (Table 5). USFS land also had a negative association with the status of salmon and fall Chinook (Table 5). Examples of extinct fall Chinook stocks in watersheds entirely blocked by dams include the Snake River and its tributaries above the Hells Canyon Dam, and the Spokane and Sanpoil Rivers in Washington. The condition of estuaries, which is very important for fall Chinook rearing (Magnuson and Hilborn 2003), is a factor not included in this study. The fact that only the freshwater phase of fall Chinook was addressed might explain the low number of significant associations between fall Chinook and anthropogenic variables on the coast and Columbia Basin when compared to other species and races (Table 5).

Winter steelhead had the lowest risk status region-wide. Their life history varies more than that of the other species studied regarding the time spent in freshwater, times of emigration and immigration to and from freshwater and the fact that they are the only repeat spawner. This variability may have served as an advantage during different times of the year and between years diminishing the potential for extinction. This species presented the highest number of significant associations with anthropogenic variables (Table 5), which could be due to the fact that they have the widest remaining distribution (96 stocks region-wide). Winter steelhead presented the second highest correlation with the number of dams below the watershed after coho (Table 5). Steelhead is a fast migratory species and can be aided by appropriate river flow to support constant flushing behavior. Transportation projects in the Columbia River Basin suggest that steelhead appear to have the best relative survival under transportation past dams (Independent Scientific Group 1997). The fact that they spawn multiple times may have served both as an advantage, by spreading the risk of mortality across habitats (Busby et al. 2000), and as a disadvantage, by exposing them more frequently to anthropogenic impacts within watersheds.

REGIONAL DIFFERENCES

When combining the status of all species and races of salmon, coastal stocks had an average status of "special concern" (rank 3) compared to "moderate to high risk of extinction, maybe already extinct" (rank 4) for Columbia Basin stocks (Table 5). Whereas in the Columbia Basin dams were the most significant variable explaining the status of salmon stocks, on the Coast other anthropogenic variables, such as Indian tribal land, wilderness areas, wild and scenic river, watershed group, and hatcheries were very significant.

On the Coast, salmon were at lower risk and more weakly associated with most anthropogenic variables than were salmon region-wide or in the Columbia Basin (Table 5). In the absence of dams, other anthropogenic factors, such as land use, hatcheries and watershed groups, were significant in explaining the status of coastal salmon. There were important factors to consider when explaining these weak associations. First, coastal stocks are supposedly more influenced by ocean environmental factors than Columbia Basin stocks (Nehlsen et al. 1991). Second, coastal salmon have shorter upstream and downstream migrations than Columbia Basin salmon, and thus are exposed to watershed variables for shorter periods of time. Despite the absence of dams on coastal watersheds, some coastal salmon stocks, such as Malibu Creek coho in California, Euchere River coho in Oregon, and Pysht River fall Chinook in Washington, have gone extinct and are in moderate to high risk of extinction. Therefore, anthropogenic impacts to coastal watersheds should continue to be researched and managed.

In the Columbia Basin, dams were more strongly associated with the status of salmon than other anthropogenic variables (Table 6). In fact, the effect of dams on the Columbia Basin actually masks the influence of other factors above dams. Impassable dams have caused extinctions of some salmon stocks independent of other anthropogenic variables affecting the watershed.

Although very important, this study does not address the influence of anthropogenic activities on neighboring watersheds and migration corridors because it classifies each watershed independently from other watersheds potentially influencing its condition, with the exception of the variable indicating the number of dams below the watershed. When studying the cumulative effects of land use on salmon habitat in southwest Oregon coastal streams, Frissell (1992) proposed that alterations in headwater areas are generally transmitted downstream, so we can underestimate the temporal and spatial scale of their impact by looking at short-term and on-site associations with anthropogenic variables. He suggested that human influence in a drainage basin should be viewed as a complex response of the interaction between human disturbance and natural perturbations in the ecosystem.

ANTHROPOGENIC VARIABLES AND SALMON

This study shows that anthropogenic variables on salmon watersheds can help explain a large portion of the variability of salmon stock status (Table 5). It is evident that there are other impacts on salmon stocks, such as harvest, ocean environmental factors (Bradford 1995), the combined effects of anthropogenic trends and climate cycles (Anderson 1999), physical and geomorphic processes (Montgomery et al. 1999), mining (Maret and MacCoy 2002), and estuarine factors (Magnuson and Hilborn 2003). However, although only some of the most frequently cited freshwater variables were included in this study, significant associations were found between them and the status of salmon stocks. When comparing the relative importance of ocean and freshwater mortality in salmon recruitment, Bradford (1995) concluded that, although mortality in the ocean is important, salmon mortality in freshwater was significant in explaining variance in number of recruits. Mueter et al. (2005) found correlations between survival rates of chum *O. keta* and pink *O. gorbusha* just prior to, during, and after out-migration to the ocean and sea surface temperatures. However, they did not find evidence of relationships between coastal upwelling and survival rates of salmon. Overall, the coastal ocean conditions that they examined explained "a relatively small proportion of the environmentally induced variability in salmon survival rates (Mueter et al. 2005)."

Dams presented the highest and most consistent association with the status of salmon stocks when all the statistical tools were used. This association supports the general opinion that dams are a major cause of salmon decline in the Pacific Northwest (Nehlsen et al. 1991; Hassemer et al. 1995; Huntington et al. 1996; National Research Council 1996; Independent Scientific Group 1997; Pejchar and Warner 2001). Dams have the greatest effect on the Columbia Basin where 22% of the watersheds are completely blocked by dams. Examples of watersheds that typify the results are the following: nearly all dammed watersheds on the Washington side of Columbia Basin, such as the Spokane River

and the Sanpoil River; watersheds in the Snake River Basin, such as the Payette River (ID) and the Malheur River (OR); a few watersheds in the Sacramento River Basin and the California Coast; and some watersheds in the Klamath River Basin have extinct stocks of spring and summer Chinook. Conversely, lower risk stocks, which were classified as healthy by Huntington et al. (1994), are present in watersheds with little or no influence of dams. Examples are the Smith, Tahekenitch, and Siltcoos coho stocks on the Oregon Coast; and the Soleduck, Bogachiel, Calawah, Hoh, Weets, and Clearwater River winter steelhead stocks on the Washington Coast. If dams block access to spawn, other anthropogenic variables become less important.

One unexpected result was the direction of the association between salmon and USFS land. The greater the amount of USFS land, the higher risk of spring, fall and summer Chinook stocks. However, taking a closer look at the meaning of this variable, I believe that in this case, the negative correlation between USFS land and the status of salmon stocks could have nothing to do with an anthropogenic effect, but instead with watershed topology and geography. A lot of USFS land is located high in the watershed above many dams. Considering the significant correlation between the status of salmon stocks and the number of dams below the watershed, it is only logical that USFS land be associated with the higher risk stocks. Difference in habitat preference between species and races can also be partly responsible for some of the results. For example, while spring Chinook tend to prefer high mountain areas for spawning and rearing, these are less favored by fall Chinook and coho. Nevertheless, land ownership and its association with the status of salmon is an important subject. In order to adequately address the effect of land ownership on the status of salmon, data on the quality of forest lands, such as information on logging practices, should be evaluated. These data were not included in this study and would be necessary to address the effect of logging observed by other researchers (Frissell 1992; Botkin et al. 1995; National Research Council 1996). It is interesting to note that lower risk spring and fall Chinook stocks were found in forested lands and non-USFS lands, which include lands under the control of the Bureau of Land Management, the US Fish and Wildlife Service, the National Park Service, and State and private lands – a very broad land ownership variable. Paulsen and Fisher (2005) also found that survival rate of Chinook salmon in the Snake River and actions to promote the health of watersheds were positively correlated with the proportion of private/BLM land.

Land use variables, indicating the proportion of urban and agricultural lands, were associated with higher risk salmon stocks. Human population size and the extent of subdivision development were associated with the higher risk status of summer Chinook, coho, and winter steelhead. Winter steelhead were the species most affected by urbanization. Agricultural lands were equally associated with higher risk winter steelhead and coho (Table 5). Other researchers found similar significant relationships between habitat modification and salmon decline. Pess et al. (2002) discovered that adult coho densities in heavily forested areas were 1.5 to 3.5 times greater than those in urban, rural, and agricultural areas along the Snohomish River, Washington. Thompson and Lee (2000) found a strong negative relationship between predicted probability of Chinook salmon parr count and medium to high density of roads in Idaho watersheds. Using data over an eleven-year period, Regetz (2003) found a strong negative relationship between salmon productivity and urban land cover in a study of 22 populations of spring and summer Chinook salmon in the Columbia River system.

Areas indicating lack of anthropogenic disturbance were associated with lower risk salmon stocks. Wild and scenic rivers and wilderness areas were associated with lower risk spring Chinook (Table 5), corroborating what other researchers found. Paulsen and Fisher (2001) determined that Snake River spring-summer Chinook parr reared in wilderness areas had a higher survival rate during their freshwater residence than parr reared in intensively managed timber lands or in areas with high road density. Magnuson and Hilborn (2003) found a significant relationship between the survival of fall Chinook and the percentage of pristine estuary available for rearing. Kershner et al. (2004) compared the state referenced watersheds (those without livestock grazing for the past 30 years, where less than 10% of the watershed had undergone timber harvesting, without evidence of mining near riparian areas, and where road densities where less than 0.5km/km2) with managed watersheds (for timber, road building, livestock, mining, and recreational purposes) on federal lands within the Columbia River Basin. They found that stream banks were more stable and undercut and the banks had steeper angles in referenced watersheds, which were found in higher mean elevation and recorded more annual precipitation than managed watersheds.

Contrary to my hypothesis and many studies that have shown negative effect of hatcheries on the health of wild salmon (Noble 1991; Lichatowich and Mobrand 1995; Nawa 1995; Chilcote 2003), lower risk summer

Chinook and winter steelhead stocks were associated with the presence of hatcheries in their watershed (Table 4). Out of the 214 stocks identified by Nehlsen et al (1991), about half (104) had a high probability of introgression with hatchery stocks. On the other hand, most (101) of the 121 healthy stocks classified by Huntington et al. (1994) have either had no fish cultural activities in their home watershed or are thought to have been exposed to little risk of reduced productivity or adaptive potential due to stock transfers or direct interaction with hatchery fish. It is important to note that when total escapement is calculated (one of the measures utilized in categorizing stocks into various status), it does not distinguish wild fish of hatchery heritage from those of strictly native origin (Myers et al. 1998). Also, because of outplanting to other watersheds it is not possible to qualify the effect of hatcheries by simple presence/absence in a specific watershed (Weitkamp et al. 1995). In order to minimize competition between hatchery and wild salmon, Oregon hatchery releases in the 1990's have consisted mainly of acclimated smolts (Kostow 1996).

Results for Indian tribal land and watershed groups were inconclusive. Indian tribal lands were positively associated with winter steelhead and negatively associated with fall and spring Chinook. Similarly, watershed groups were positively associated with summer Chinook but negatively associated with coho and winter steelhead. I believe that the effects of these groups on salmon cannot be evaluated by their simple presence or absence in the watershed where stocks spawn. Some watershed groups may be large and very active at local scales; others may exist largely on paper or be too small to be of any meaningful consequence. Similarly, some Indian tribes may be involved in various salmon restoration projects, while others may promote activities that are detrimental to wild salmon. More detailed, temporal studies addressing the effectiveness of these human organizations in promoting the health of the watershed would be appropriate. One example of a success story, as stated by Columbia River Inter-Tribal Fish Commission (1996) is the salmon's return to the Umatilla River, Oregon, where coho and Chinook salmon stocks were extinct by 1920. Some of the strategies of the cooperative plan between the Umatilla Indian Reservation, Oregon Department of Fish and Wildlife, Bonneville Power Administration, the US Bureau of Reclamation, Umatilla County, and the City of Pendleton, include putting more water in the river through pumping and water storage; improving fish passage at the Three Mile Dam with fish screens, fish ladders, and transportation of juvenile fish; improving the water quality of stream; reducing streambank erosion; and reintroducing salmon through hatchery production (Columbia River Inter-Tribal Fish Commission 1996). Are watershed groups a symptom of problems or a cause? This is a question for further study.

CONCLUSIONS

Anthropogenic variables chosen for this study were strongly associated with the status of salmon stocks in watersheds where they spawn, corroborating the fact that the fresh water existence of salmon is of much importance in determining their status. The more anthropogenic activity in a watershed, the worse the status of salmon stocks while the lack of activity in wilderness and wild and scenic river areas was associated with lowest risk salmon stocks. Dam status was the only variable associated with the poor status of all species and races of salmon.
The presence of hatcheries in a watershed was associated with lower risk salmon stocks but more detailed information is needed regarding the effect of hatcheries on wild salmon. USFS land was associated with higher risk salmon stocks but the location of these lands high in the watershed and above many dams can be the reason for such association. Life history characteristics, such as time of spawning and length of freshwater residence, helped understand some of the associations between various species and races of salmon and anthropogenic variables. Columbia Basin stocks were in worse shape than coastal stocks. Status of coastal salmon was associated with land use variables while Columbia Basin salmon stocks were significantly associated with dams and land use variables. Although the results of this study show that dams are the anthropogenic variable that is most strongly associated with the status of salmon independent of the species or race, they are not the only variable associated with higher risk stocks. Continued attention must be given to improving the survival of salmon past dams and to improve the quality of habitat in dammed watersheds. Our challenge is to learn from our experiences and try to manage our resources and their ecosystem in a wise manner.

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DISCLAIMER AND NOTE

The views expressed herein are those of the authors and are not to be construed as official or reflecting the views of the U.S. Coast Guard or any agency of the U.S. Government

APPENDIX: Examples of watersheds followed by the status of various species (Nehlsen et al (1991) and Huntington et al (1994)) and races of salmon and anthropogenic variables in that watershed. Please refer to coding of variables in Table 2 and Methods.

****Relative size of watersheds (e.g. 1= very small creeks, 5 = large watersheds), na = no stock of that species and race reported in that watershed.***

WATERSHED NAME (WATERSHED SIZE)*	STATE	FALL CHINOOK	SUMMER CHINOOK	SPRING CHINOOK	COHO	WINTER STEELHEAD	DAM STATUS	NUMBER OF DAMS	FOREST LAND	USFS LAND	NON- USFS LAND	WILDERNESS	WILD AND SCENIC R.	TRIBAL LAND	AGRICULTURAL LAND	SUBDIVISON DEV.	HUMAN POP.	HATCHERIES	WATERSHED GROUP
Hanford Reach (5)	WA	1	na	na	na	na	1	4	1	5	5	5	5	5	1	2	2	1	1
John Day, mainstem (5)	OR	na	na	3	na	na	1	3	4	4	5	4	2	5	3	1	1	1	1
Umpqua, North (2)	OR	na	na	2	na	2	2	0	3	4	4	4	3	5	3	2	2	5	5
Smith (2)	OR	2	na	na	2	na	1	0	2	4	3	5	5	5	2	1	1	1	1
Payette (2)	WA	na	5	5	na	5	3	12	3	3	5	5	5	5	4	1	1	1	5